Discovery of a 2 Kpc Binary Quasar [1]

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Abstract.
LBQS 0103−2753 is a binary quasar with a separation of only 0.3 arcsec. The projected spacing of 2.3 kpc at the distance of the source (z = 0.848) is much smaller than that of any other known binary QSO. The binary nature is demonstrated by the very different spectra of the two components and the low probability of a chance pairing. LBQS 0103−2753 presumably is a galaxy merger with a small physical separation between the two supermassive black holes. Such objects may provide important constraints on the evolution of binary black holes and the fueling of AGN.

INTRODUCTION

Binary QSOs occur at a rate of about one per thousand QSOs [12,15]. Typical angular separations are $3''$ to $10''$. True binaries, as opposed to gravitational lenses, may be recognized by different radio emission or different emission-line or BAL characteristics in their component spectra [15,18]. Binary QSOs presumably represent galaxy encounters in which tidal interactions have led to an enhanced probability of nuclear activity [8]. Such events may offer important insights into the fueling of AGN and the timescales for the mergers of galaxies and their central black holes [3].

In the course of a study of QSOs with broad absorption lines (BALs), we have discovered that LBQS 0103−2753 is a binary QSO with a separation of only $0''.3$ [14]. This corresponds to a physical separation of only 2 kpc. The closest previously known binaries have spacings of 15 kpc or more [7]. Such a close spacing suggests

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an advanced merger, with the two supermassive black holes well within the nascent bulge of the merged galaxy.

OBSERVATIONS

LBQS 0103−2753 is one of eight BALQSOs included in a study, by the authors, of the ultraviolet spectra of BALQSOs at moderate redshift with the Space Telescope Imaging Spectrograph (*STIS*) on the Hubble Space Telescope (*HST*). The object has an emission-line redshift $z_e = 0.848$ and an apparent magnitude $B_J = 18.1$, and its LBQS spectrum shows broad absorption in Mg II $\lambda 2798$ [17]. Figure 1 shows the STIS CCD acquisition image. The A/B flux ratio is 3.1, implying magnitudes $B_J = 18.2$ and 19.4 for components A and B, respectively. The FWHMs of the images are consistent with point sources, and the separation is $\Delta\theta$=0.295 $\pm$ 0.011 arcsec in position angle $+30.1° \pm 2.2°$ (A northeast of B).

A $52''$ by $0\farcs2$ slit was used for the spectroscopic observations (Figure 2) with the STIS NUV–MAMA using the G230L grating. The QSO pair was, by luck, almost perfectly aligned with the STIS slit, itself aligned along the image +y axis. The resolution at 2400 Å is 3.3 Å FWHM.

We obtained an optical spectrum of LBQS 0103−2753 (sum of both components) in August 1998 using the CTIO Blanco 4m telescope. The spectrum [14] shows a dramatic weakening of the Mg II Bal, which is unusual [13].

LBQS 0103−2753: A CLOSE BINARY QSO

LBQS 0103−2753 A has strong BALs of C IV $\lambda\lambda 1548$,1551, Si IV $\lambda 1400$, N V $\lambda 1240$, and O VI $\lambda 1034$ that are absent in the spectrum of component B. In addition, the two components have very different emission-line properties. This

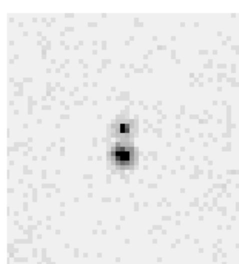

FIGURE 1. Acquisition image of LBQS 0103−2753 obtained with the STIS CCD. The brighter object is A, the BALQSO, and the fainter is B. Reproduced from Junkkarinen et al. (2001) with permission.

effectively rules out the possibility that the object is a lensed QSO. Junkkarinen et al. [14] argue that the likelihood also is small that LBQS 0103−2753 is a chance alignment of a wider binary of the 3″ to 10″ (∼40 kpc) variety.

Could LBQS 0103−2753 be a chance superposition of two unrelated QSOs? The emission-line redshifts of the two components, though similar, differ by more than the 600 km s^{-1} difference typical of binary QSOs [15]. The redshift of B is well determined at $z_B = 0.858$, but the BALs and emission-line profiles of component A make the emission-line redshift quite uncertain. The C IV line gives $z_A = 0.834$, which corresponds to a velocity difference from z_B of 3900 km s^{-1}. However, C IV emission lines are often blueshifted from the systemic redshift [9], especially in the case of weak, low contrast lines as in component A [6]. How likely is a chance coincidence of a QSO as bright as the apparent magnitude of component B within this redshift range and within an angular separation of 0″.3? We take a surface density of 10 QSOs per square degree between B = 18.2 and 19.4, for QSOs with redshifts $z < 2.2$ [4]. If we assume these are distributed roughly uniformly with redshift, then the odds of having a second QSO within 0″.3 of a given QSO, and with a redshift difference not more than $\Delta z = z_B - z_A = 0.024$, is $10^{-8.6}$. If ∼500 QSOs

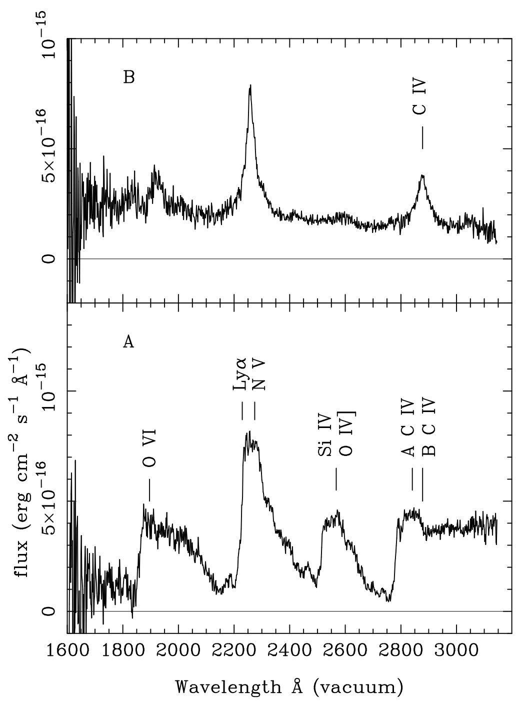

FIGURE 2. Spectra of LBQS 0103−2753 A and B obtained with HST/STIS using the NUV–MAMA and G230L grating. The upper panel is component B and the lower panel is component A. The measured C IV λ 1549 emission-line wavelengths for components A and B are both shown with vertical marks above component A's CIV λ 1549 emission line. Reproduced from Junkkarinen et al. (2001) with permission.

have been observed in a way that would reveal such a binary (see below), then the odds of having one chance alignment resembling LBQS 0103−2753, among all these targets, is only $10^{-5.9}$. This supports the conclusion that LBQS 0103−2753 is a true, physical binary.

DISCUSSION

The greatest number of opportunities to discover a pair like LBQS 0103−2753 appears to be offered by the *HST* snapshot survey for gravitationally lensed QSOs [16]. This involved 498 QSOs with $z > 1$ and $M_V < -25.5$ (H_0=100, q_0= 0.5). The snapshot survey could have detected a binary with the characteristics of LBQS 0103−2753 [1]. However, it did not find any binary QSOs with separations less than $1''.0$. From the one example of LBQS 0103−2753, we therefore estimate a rate of roughly 1/500 for separations $\sim 0''.3$. This in turn suggests that there are ∼10 unrecognized binaries in the $0''.3$ range among the $\sim 10^4$ known QSOs.

Junkkarinen et al. [14] suggest that LBQS 0103−2753 represents an advanced stage of a galactic merger. The cores of the two galaxies are merging, and the black holes are settling into an orbit of radius similar to the observed spacing of 2 kpc. The wider binaries observed, with physical spacing of ∼20 to 100 kpc, likely represent mergers at an earlier stage. Simulations of colliding disk galaxies [2] indicate that gas accumulates in the nucleus of each galaxy as the two orbit away from each other after the first close encounter. The duration of this first large orbital loop is $\sim 10^{8.5}$ yr. Dynamical friction causes rapid decay of subsequent loops, and the central regions of the galaxies merge quickly. The final merger involves a massive concentration of gas in the nucleus capable of fueling powerful starbursts and AGN activity. Junkkarinen et al. [14] estimate the masses of the black holes and the properties of the host galaxies from the QSO's luminosities and the relationship between black hole mass and bulge properties of the host galaxy [10]. This leads to an estimated lifetime of the binary black hole orbit, at the observed 2 kpc spacing, of only $\sim 10^7$ years. This in turn suggests that the probability of a merger being active as a binary QSO is larger during the 2 kpc stage than during the 40 kpc stage.

Ultraluminous infrared galaxies (ULIGS, $L_{ir} > 10^{11}$ $L_\odot$) typically involve galactic mergers [19,11]. Interestingly, the mean nuclear spacing of ∼2 kpc is similar to that of LBQS 0103−2753. The brighter ULIGs are believed to be powered predominantly by AGN. LBQS 0103−2753 is distinguished from typical ULIGs by the lack of heavy extinction, as well as an exceptionally high luminosity. Infrared observations of LBQS 0103−2753 would be valuable to determine whether massive amounts of dust are still present in the vicinity of the QSOs.

OTHER UNRESOLVED BINARY QSOS?

We have estimated that binaries as close as LBQS 0103−2753 occur with a frequency of $\sim 10^{-3}$. Given this low incidence, searches for $0''.3$ binaries would benefit from any criterion to narrow the list of candidates. Until our *HST* observations, LBQS 0103−2753 was not, to our knowledge, suspected of being a binary QSO. The great diversity of QSO spectra makes it difficult to specify spectroscopic criteria with which to identify candidate binaries. Objects with double peaked narrow line emission ([O III] λ5007 or [O II] λ3727) might include some candidates. Composite broad emission-line profiles of an unusual character might also be an indicator, e.g., the QSO B340 [20]. Ideally, one could identify two properties of QSOs that almost never occur together. The rare exceptions would then be candidates for unresolved binaries. One possibility might be BALQSOs with strong, unabsorbed soft X-ray fluxes; BALQSOs as a class show weak soft X-ray fluxes, relative to the optical continuum, evidently because of absorption [5].

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